PROCESS-BASED SIMULATION LIBRARY FOR CONSTRUCTION PROJECT PLANNING

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ABSTRACT

This paper presents a process-based discrete-event simulation library for construction project planning. Business process models are used to build an accumulative knowledge base for standard construction processes in form of a ready to use process templates. The library aims to reduce the time and efforts needed to create simulation models for a construction project throughout its lifecycle by integrating process models with simulation models and provide a set of reusable simulation components. The paper presents the concepts and describes the architecture of the system with briefly review of its features.

1   INTRODUCTION

Construction simulation has been successful in academic research with limited successful applications in industry (AbouRizk 1995, Kamat and Martinez 2001). Simulation as a planning technique for construction projects has not been widely adopted within the construction industry for many reasons, (1) lack of simplicity compared to tradition planning methods, (2) time, cost, and skills required to build and analyze simulation models (Lucko et al. 2008). Though this fact, it has been also recognized that the construction industry is progressively investing in the adoption of IT tools.

In the academic research area many principles and simulation environment have been developed since the first efforts by D.W. Halpin in 1977 by introducing CYCLONE as modeling method for construction operations (Halpin 1977). Most applied methodologies based on Discrete-Event Simulation (DES) method and were adopting as Special Purpose Simulation (SPS) targeting a special kind of construction projects like earth moving (Hajjar and AbouRizk 1996), road construction projects (Castro and Dawood 2004), or as generic simulation models, for example by integrating a constraint solver within a DES environment (König et. 2007). Most simulation systems provided the end user with the possibility to create new construction process templates graphically or in a form of process pattern in tables to describe the logic of tasks sequence inside a single process or to get a hierarchical process models. However most systems failed to simulate large-scale industrial construction having shortcomings due lack of standardization, computing ability, and simulation re-use (Wang et al. 2005).

The goal of this ongoing research is to develop dynamic simulation models rapidly to be used as support tools to evaluate scheduling and resource planning alternatives and improve resource utilization rates in order to minimize the total project duration/cost.

The presented simulation system offers many features to minimize efforts to create simulation models and validate the simulation results:

- Using formal business process models to capture and organize the knowledge in construction domain and providing the ability to transform those models directly into a simulation process library. This knowledge will be shared and ready to use for all simulation models.
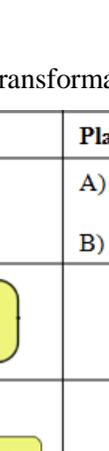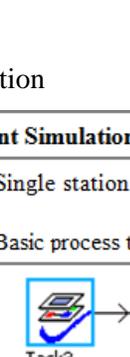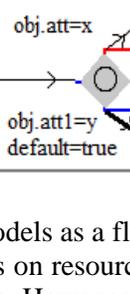
- Automatic generating of detailed project schedules by using filter process templates and dynamic links with Building Information Model (BIM).
- 4D visualization of construction activities.
- Monitoring the resource utilization and material usage during simulation.
- Import/Export interfaces to integrate projects data easily and validate the results.
- Predefined simulation experiments for important simulation parameters.

2 BUSINESS PROCESS MODELS AND SIMULATION MODELS

Business Process Modeling Notation (BPMN) is a graphical representation for specifying business processes in a business process model. The modeling in BPMN is made by simple diagrams with a small set of graphical elements. It should make it easy for business users as well as developers to understand the flow and the process. In our proposed approach we use BPMN diagrams to describe the construction processes and then transform them into the simulation tool "Plant Simulation" (UGS Tecnomatix) as simulation process templates (Wagner et al. 2010).

An XML parser is used to transform BPMN elements like task, gateway, and sequence flow into corresponding elements inside the simulation library. Table 1 shows some examples for such transformations.

Table 1: Current scope of transformation

These transformations are restricted to the functionality of process models as a flow chart. Process models as used in our approach are generic in such a way that no attention is on resources and time, i.e. they are focused on the process logic and the general technological constraints. However simulation models are to focus on resources, time, and other project specific constraints. Therefore the above transformations have to complement with simulation specific extensions. In the following we present three kinds of process templates used inside the simulation system namely basic process templates for single activities, compound process templates for multiple activities, and filter process templates.

2.1 Basic process template for single activity

The single activity or task is the basic element of the process model to do a work or progress. Furthermore it needs in the simulation model resources and has to meet conditions to be allowed to start (Figure 1 left side). At first all start conditions (e.g. relations with other tasks or calendar constraints) and availability of minimum required resources will be checked. If any of these constraints is not satisfied the status of the task will be changed to "waiting for other tasks" or "waiting for resources" and a waiting loop will be activated.
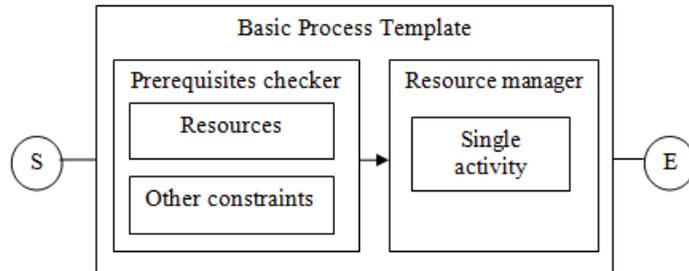
Figure 1: Structure of basic process template for single activity

When all constrains are satisfied the required resources will be acquired and the status changes to "started". The activity duration can be defined inside the process template as constant/stochastic time value, or mathematic formula (e.g. work amount / productivity coefficients). Required resources can be defined as groups of resource combinations with standard, minimum, and maximum values for each single resource.

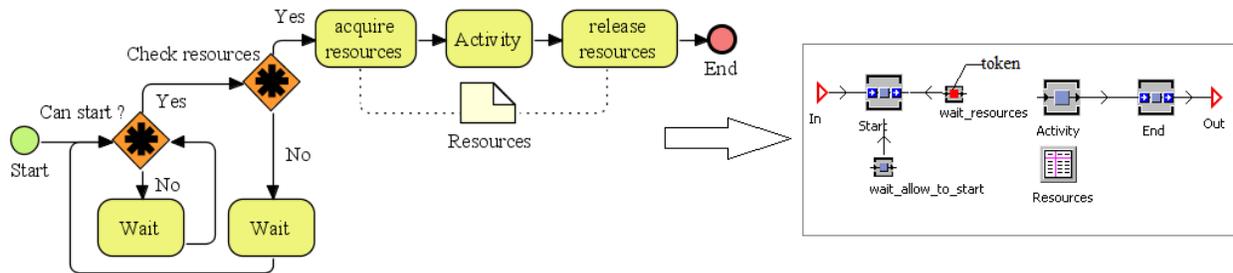Figure 2 shows the BPMN diagram of the basic template.

Figure 2: Basic process template for single activity as BPMN (left) and as simulation model (right)

The basic process template is the super class of all other process templates for single activities inside the process library. The basic template will be used by default when the process template of a certain task is not given explicitly.

Waiting loops give the active process instances during the simulation the behavior of agents. They can communicate with each other to check starting constraints and communicate with a resource manager to check the availability of theirs required resources without any further interaction. Having a lot of active process instances with active waiting loops may affect the performance, therefore a special attention was made regards this issue during the implementation. The first waiting loop will be deactivated after the first run if any of its predecessors did not exist or it exist but did not finish yet. Each task activate the first waiting loop for its successors when it finish, with help of this mechanism the number of required loops to check the tasks dependencies is minimized tremendously. The second loop which proves the availability of resources has been integrated with the process/resources calendar definition to avoid doing any re-

dundant loops. The default interval time for both loops can be adjusted according to the task priority and type of required resources.

2.2 Compound process templates

The basic process template for single tasks can be combined with other process elements like gateways, buffers, and other tasks to create a compound process template. Compound process templates represent a sequence of tasks, such as erecting of concrete walls which are a subsumption of many single tasks but they have one logic in common (Figure 3). With the construct of a compound process templates aggregated process object can easily defined and hence a process-based simulation library for hierarchical process development can be established.
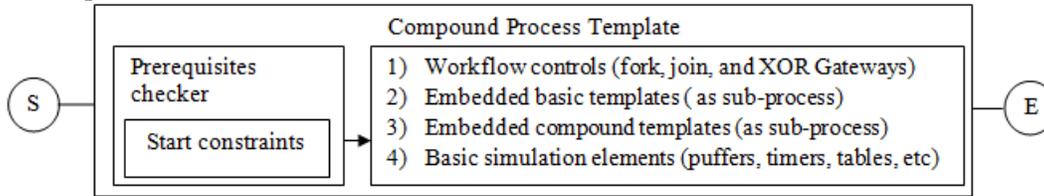

Figure 3: Structure of compound process template for multiple activities

For compound processes only starting constraints like relations with other tasks or calendar constraints (e.g. daily work time, weekends, and holidays) will be checked. Each single activity inside the process template will check for its individual required resources by itself. Using fork and join gateways allow the parallel executing and synchronization of multiple activities. XOR data-based gateway can be used to control the flow of process executing depending on a conditional expressions. After mapping the process model into simulation process library all basic simulation objects can be added to the process template, for example puffers to represent queues inside the process, functions and information objects to collect data during simulation.

Figure 4 shows an example of a compound process template for erecting a reinforced concrete column. The process consists of four single activities (install formwork, steel work, concrete work, and remove formwork). Two gateways are used to allow executing "steel work" and "install formwork" parallel.
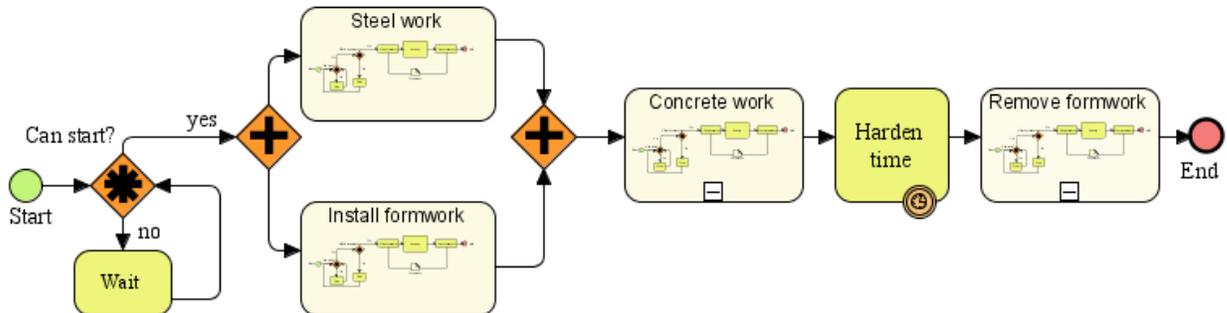

Figure 4: Example of compound process template for erecting a reinforced concrete column

This process template can be further extended to include different construction methods depending on the element material (concrete, steel) or construction method, or to be included again in a higher process templates.

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2.3 Filter process templates

Filter process templates are used to generate the work breakdown structure (WBS) of the structural work semi-automatically when only a rough project schedule is available. For each construction project there are many schedules with different aspects and level of detail, one of the early and important once is the contract schedule which comes out as an agreement between the project owner and the construction company, it has usually few entities as milestones to define the expected dates to start and finish important activities (Figure 5). The planer in the construction company starts with this schedule to create more detailed schedules taking in account the following information:

- Available resources for this project
- The amount of structural work in each work section (total concrete volume, total framework areas, number of building elements)
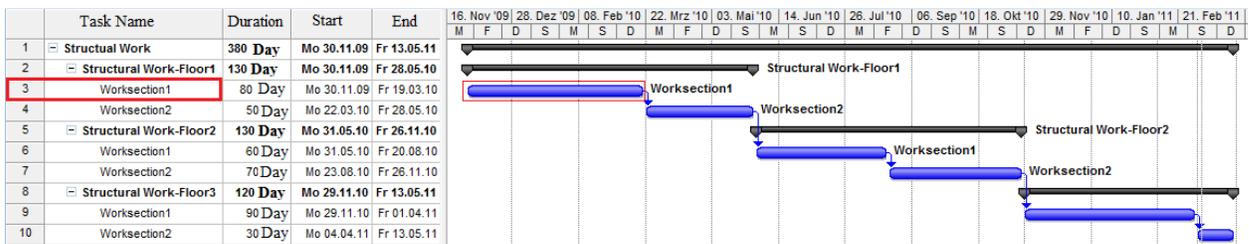- Experiences gained from similar completed projects

Figure 5 Example of project schedule for structural work in a three floors building

Filter process templates can be used here to break the project schedule one or more levels down. Each task (related to structural work) in the high level schedule will be linked with a filter process template and provided with a filter expression to obtain only the related elements of the BIM model according to BIM filter specifications (Katranuschkov et. al. 2010).
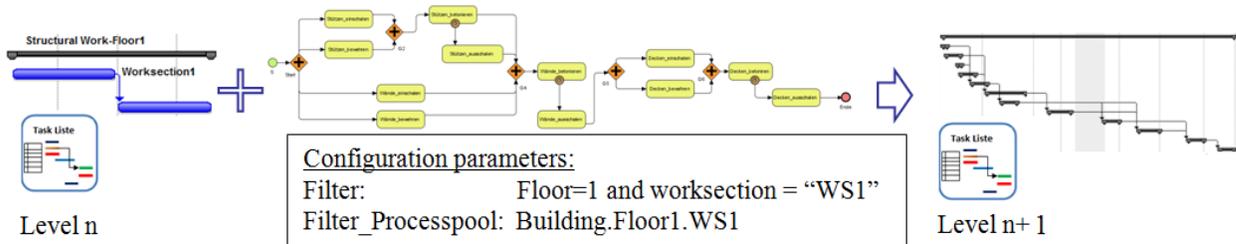

Figure 6: Automatic generating of workloads using filter process templates

The selected filter process template serves as a recipe to describe the logic and steps needed to achieve the work within each task. We consider as an example the task #3 "Structural work-worksection1" inside floor1. For this task we should assign the following filter expression to our selected filter process:

```
Filter = "o.floor = 1 and o.worksection='WS1'"
```

This filter expression will be evaluated during the simulation for each building element as a Boolean expression with expected result to be "true" or "false", only building elements which fulfill this filter will be included inside the automatic generated workload.

Using filter process templates with dynamic links to BIM model offers many advantages compared to manual methods used to prepare detailed project schedules:

1. Changing the building design will be reflected automatically in the filter result, for example adding or removing building elements.

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2. Filter expressions offers high flexibility. We can use almost any mathematical operation in conjunction with building element attributes inside the expression, for example using the elements coordinates(x, y, z) to divide the building virtually to work sections and zones, or other attributes like volume, area, and materials to include or exclude certain elements.

3. The re-usability of filter process template for similar tasks across many projects

Figure 7 shows an example of a filter process for structural work inside a work section as BPMN diagram, to keep the process simple only walls, columns, and slabs which are made of reinforcement concrete are included.
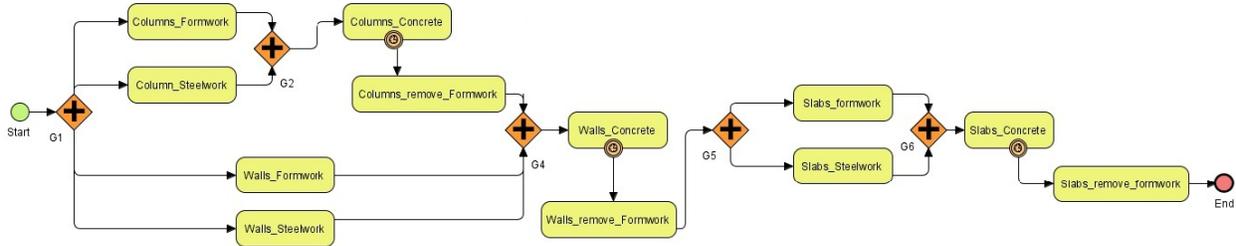

Figure 7: A typical process model for construction work inside a work section

As a result a list of single tasks will be generated with all required configuration parameters. Each task will be linked with a process template and a certain building element. Relations between tasks will be also provided automatically. Using filter process templates saves a lot of time and avoids making errors. Different construction strategies or different arrangement of work sections can be compared by applying changes to the process template or the filter expression and regenerate the tasks list.

3   SYSTEM ARCHITECTURE AND IMPLEMENTATION

A prototype implementation for the process-based proposed approach was carried out using the discrete-event simulation tool "Plant Simulation". The simulation model has a modular structure to handle the big size and complexity of the information to be modeled(Figure 8). Each simulation model consist of input components to integrated the input data from different resources (building elements, resource pool, task list) and output components (drawing panels, Gantt charts, 3D exporter) to validate the simulation results.
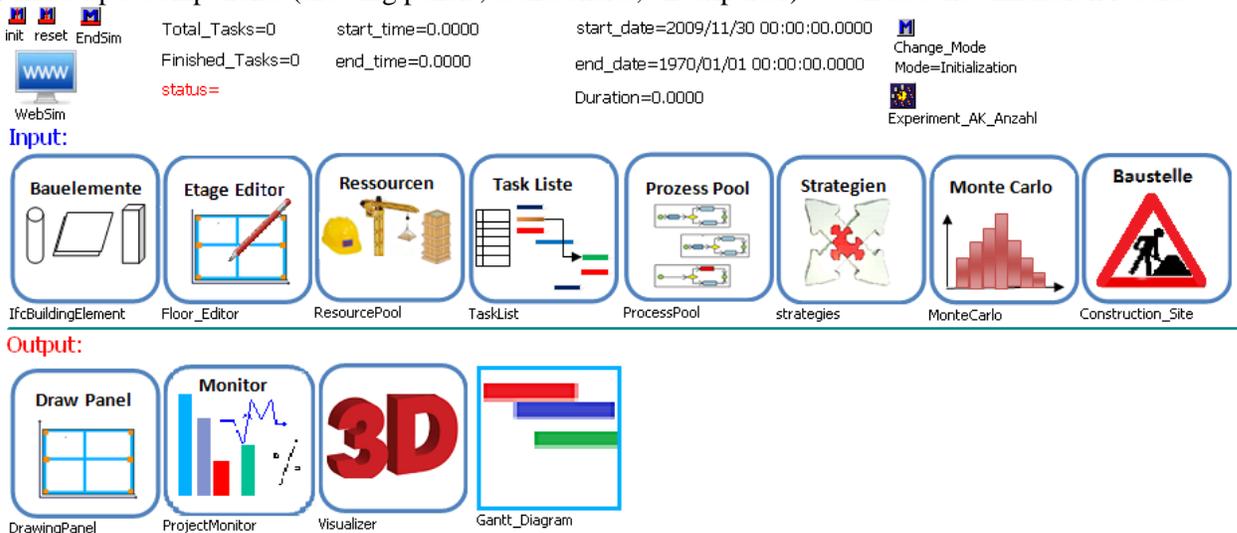

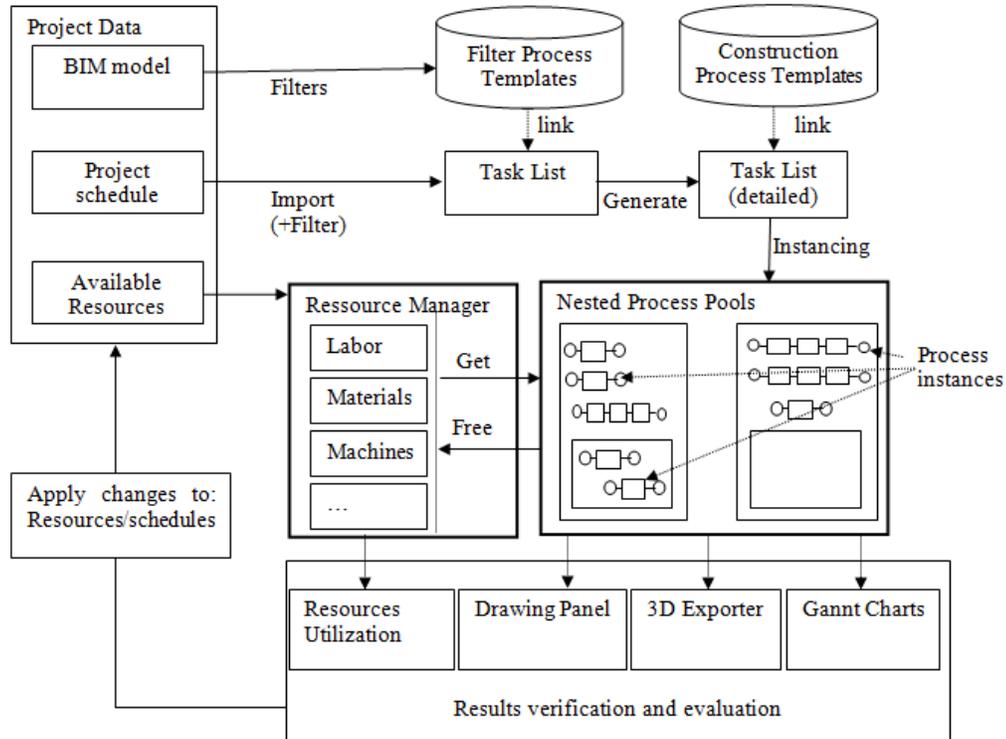Figure 8: A set of the input/output simulation components as ready to use simulation model template

Figure 9: System architecture

In the following sections a brief description of the most important components are provided.

3.1   Task List:

Tasks are the central elements of any project schedule, whereas activities are defined as single or compound tasks (e.g. erect all columns in 1st floor) with a planned start time and duration. Task list component is used to define the list of all construction tasks inside the simulation model. For each task the planned start time is defined while the actual start time and task duration will be calculated during the simulation. To add a new task we need to give a name, start time and select an appropriate process template, some other configuration parameters may be required depending on the task type. Figure 10 shows the XML schema of tasks.
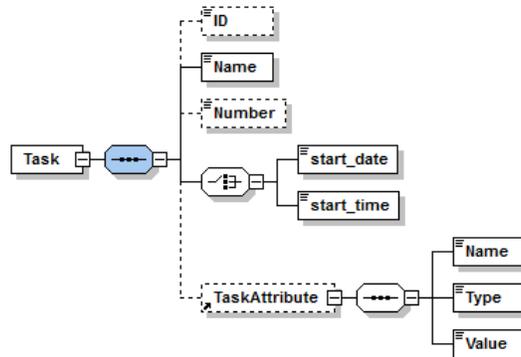

Figure 10: Data structure of tasks

Links between tasks and process templates or building elements is made through passing configuration attributes. Table 2 lists some of those attributes.

Table 2: List of configuration attributes for tasks

Attribute name	Description
Process Template	To link the task with a certain process template inside the process library i.e. "Proceses.StructuralWork.Column.InstallFormwork"
Predecessor , predecessors List	Define the predecessors of this task (one or many predecessors) ("-1" to define the last created task as predecessor of the current task)
BuildingElement_ID, globalId	Linking the task with a certain building element through its unique ID
ProceePool	The hierarchy path where the task instance will be created i.e. Building.Floor1.Worksection1.Columns
Duration Duration_min, Duration _max Duration_formula	Information about the task duration to override the default value inside the selected process template
Resources	Define extra resources to be used with this task
Resource Pool	To override the default resource pool component

During the simulation an instance of the process template for each task will be created inside its process pool. The creation time is equal to the scheduled start time. A token(moving unit- MU) will be placed on the "Start" element of the process instance and all configuration attributes will be considered (e.g. links to a certain building element, extra required resources, task's predecessors, etc)

A simple example of 10 tasks related to each other with "finish to start" relationship and uniform distributed duration function is shown in Figure 11.
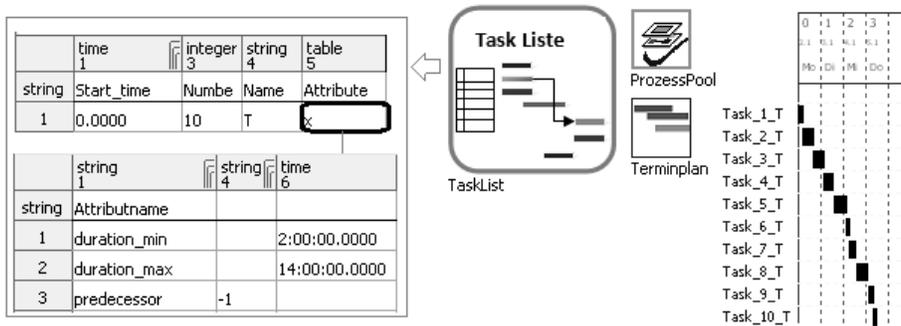

Figure 11: Example of a task list for 10 single tasks with finish-to-start relationship

Project schedules made with Microsoft Project ® can be imported to the "Task list" component automatically

3.2   Resource Pool:

The resource pool is a manager and container for all resources. It includes standard resources used in construction domain like labors, equipments, and building materials or any kind of resources, which can be added in a generic way. The availability of resources is defined as delivery tables (time, amount, attributes) so level of resources can vary over time in a planned manner.
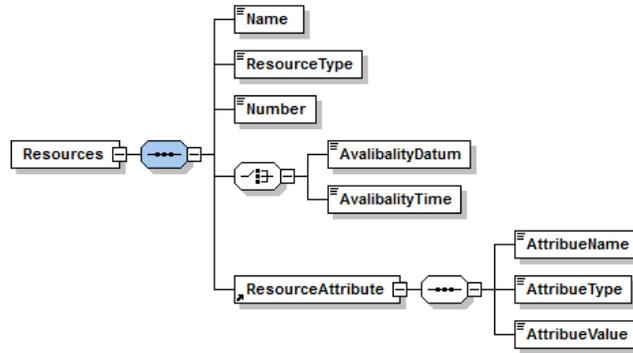
Figure 12: Data structure of resources

At the time of writing four resource-use patterns can be used:
1. The resource is used only once: material resources
2. The task acquire the resource for the whole time and release it when the task is completed : labors, small equipments
3. The task acquire the resource only for limited time : transport material by tower crane
4. One task acquires a resource and another task releases it later: install/remove formworks.

The resource pool is used also to define new calendars, daily working time and options to relax resources. Relaxing a certain resource or all resources is possible, this option is important to find out the shortest possible duration to complete a project or to analyze the influence of key resources.

User-defined calendars can be linked to process templates to define time constraints for each process.

3.3 Process Pool

The process pool is a core component of the simulation model. It works as a container for all process instances during the simulation time. It has a hierarchy structure, can contain sub process-pools and process instances. The status of each process pool changes automatically to "finished" when all included processes and sub process pools are finished, this mechanism helps to track the current state of all processes in hierarchy way and ensure the dependencies between different tasks. The names of sub process-pools and process instances inside each process pool are unique, absolute paths of process instances or sub-pools can be used inside the task list component to define the predecessors of other tasks.

The hierarchy structure of the process pool is not restricted in any way, however it is recommended to use a similar hierarchy structure of the real project and to create sub-pools for each summary task in the project schedule, for example:

```
Project.Site.Building.Storey.WorkSection.Activity.BuildingElement
```

This will help to define the relationships between tasks easily and to validate the output (Gantt bar charts for example) against the primary project schedule.

Figure 13 shows as an example the structure of a process pool component for a multi stories building during the simulation. Each storey has a sub-process pool which includes sub pools for different work sections and construction work for different kind of building elements.
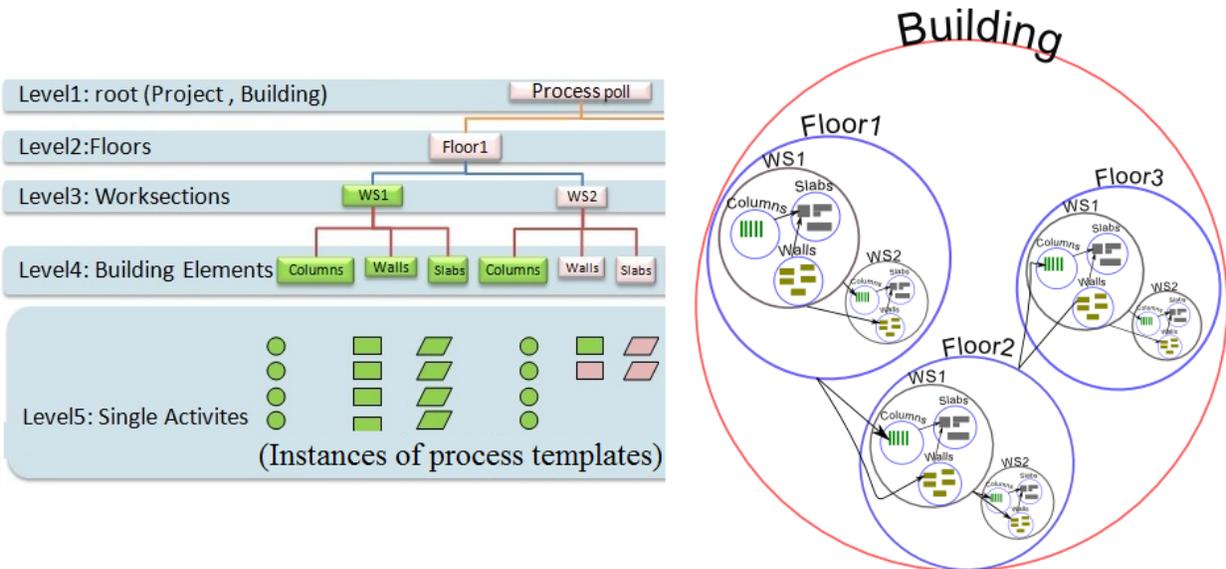
Figure 13: Example of process pool structure for a three floors building

3.4   Drawing Panel

This component offers a 2D drawing panel to visualize the progress of construction with time. Each construction process is assigned to a drawing-panel object so it can draw new graphic objects with different colors to reflect the current state of the building element and the allocation of resources. The progress of construction operations can be saved as a series of images for a visual verification.
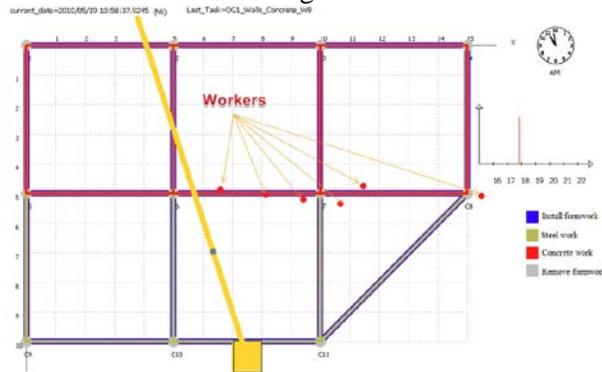

Figure 14: Drawing panel component

3.5   3D Exporter

Simulation results can be exported as 3D models in order to visualize the progress of construction operations at any time or within a specific time intervals (days, weeks, etc). The open and standard 3D format COLLADA (www.collada.org) has been used to ensure the interoperability with a wide range of graphic software. Different colors and degree of transparency are used to show the status of building elements.
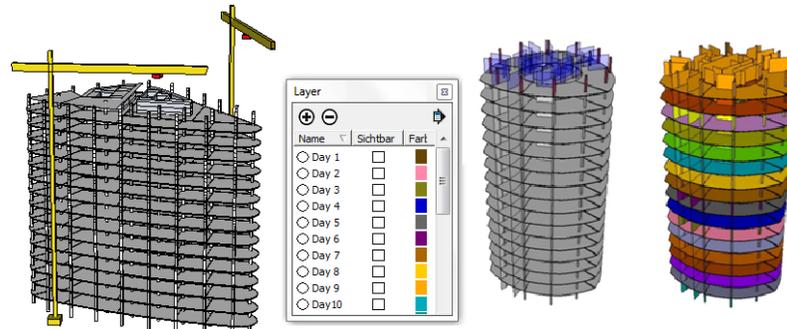
Figure 15: 3D Exporter results imported to Google SketchUp®

4 CONCLUSION

The paper has proposed using BPMN models as a formal description for construction processes. Examples of possible applications of this approach for simulation in construction domain was provided for case of single tasks, compounded tasks, and as a support tool to generate detailed schedules. A briefly review of the system architecture and its main components was covered.

The results of the prototype implementation were promising regards reducing the time to create simulation models, the ease of use, and results validation. Researches is on-going developing simulation models for real construction projects using this approach and integrate it within a project management platform to support decision making in large scale construction projects (S.-E. Schapke et. al. 2010).

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